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United States
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Forest Service



Winter 1981-82
Volume 43, No. 1

Fire Management Notes



Fire Management Notes

An international quarterly periodical devoted to forest fire management

United States
Department of
Agriculture
Forest Service



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Cover: Fire rages on hillside in Guam. Story begins on page 3.

Wildland Fire on Guam

Scott J. Josiah

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The indiscriminate use of fire in the wildlands of Guam has been a powerful force affecting the island's natural resources for the past four centuries. The use of fire on Guam for cooking and making pottery was an ancient and acceptable practice. With the coming of the Spanish (and their livestock) in the late 1500's, fire began to be extensively used in the wildlands for the creation and maintenance of pasture land. Since that time, Guam's fragile island ecosystem has suffered great damage from the unrestricted use of fire.

The island of Guam, an unincorporated U.S. Territory, is 35 miles (56 km) long by 8 miles (12.8 km) wide, and is 3,700 miles (5,900 km) west-southwest of Hawaii and 1,500 miles (2,400 km) east of the Philippines. Located in the humid tropics, Guam experiences a significant seasonal variation in rainfall. This variation creates a 6-month wet season from June to November, and a 6-month dry season from December to May. Annual rainfall totals approximately 85 in (216 cm) with roughly 75 percent falling during the wet season. Dry season weather usually consists of widely scattered, early morning showers of less than one-tenth of an in (.25 cm) with partly cloudy skies and brisk trade winds. The island's 135,000 acres (54,600 ha) are almost equally divided geologically: the northern half consists of an uplifted limestone plateau,

and the southern half is rugged, mountainous terrain of volcanic origin. The northern region supports a highly variable and unique forest and grass cover, which occasionally burns. The extensive southern savannas are sites of serious wildland fires (fig. 1).

Approximately 5 to 10 percent of the 83,000 acres (33,200 ha) of land under wildland fire protection burn each year (table 1). Far more land is burned per unit area protected than anywhere else in the United States. The peculiar combination of vegetation, climate, and sociological factors help to create an explosive wildland fire situation each dry season.

The predominant fuels over 34,000 acres (13,760 ha) of southern Guam are pure and

mixed stands of tropical grasses adapted to periodic fire. Swordgrass, *Miscanthus floridulus*, a robust perennial with extremely sharp leaves, often occurs in dense, pure stands 10 to 13 ft (3–4 m) in height. Over a period of 2 to 3 years, large amounts of organic material are produced (exceeding 20 tons/acre, 8.92 tonnes/ha) much of which dies and remains suspended among the living portions of the plant. The resulting dead fuel-to-air ratio is ideal for rapid burning. Mission grass or foxtail, *Pennisetum polystachyon*, also commonly occurs in the southern savannas. It grows up to 6 ft (2 m) tall annually, but does not produce as heavy a fuel load or as intense fire behavior as swordgrass. Foxtail, which was



Figure 1.—Extensive tropical grasslands cover much of the rugged and steep mountains of southern Guam. Limited access and rough terrain severely reduce fire suppression.

Table 1.—Causes of wildfires on Guam, 1979–81

Causes	1979		1980		1981 (Through June)		Averages (1979–81)	
	No. of fires	Acres burned	No. of fires	Acres burned	No. of fires	Acres burned	No. of fires	Acres burned
Smoking	66	227	59	307	94	411	76	315
Debris burning . .	71	1,546	56	714	121	779	83	1,013
Incendiary	255	3,992	155	2,348	220	4,428	210	3,589
Other (children, campfires, equipment). . .	160	1,675	33	134	37	563	77	790
Totals	552	7,440	303	3,503	472	6,181	446	5,707

introduced during World War II, is spreading rapidly, crowding out the swordgrass in many places.

In spite of the high humidity (typically 50 to 60 percent), intense wildland fires occur due to strong solar radiation, brisk trade winds, and heavy fuel accumulations. In pure stands of swordgrass on level terrain with a 10- to 15-mi/h (16–24 km/h) wind at 88°F, it is not unusual for flame heights to reach 33 to 45 ft (10–15 m) with rates of spread of 26 to 33 sq ft (8–10 m) per minute. Much greater flame heights and faster rates of spread have been experienced on sloping topography and/or with higher wind velocities (fig. 2).

The vast majority of fires burn hot enough to consume most of the ground vegetation and litter. Full exposure of the very fine volcanic clays to the heavy rains causes severe sheet erosion, and poses long-term problems for future land use. Large areas of southern Guam have been de-



Figure 2.—Swordgrass, the most common fuel, is extremely flammable. Its rapid growth during the wet season produces heavy fuel accumulations and, subsequently, intense fire behavior.

graded to barren, actively eroding land, losing over 1 in (2.5 cm) of soil per year (fig. 3). Subsequent sedimentation of the coral reef

ecosystem has reduced the vital fishery productivity. Ground water storage capability continues to decrease due to poor infiltration and increased overland flow. The resulting flood-drought cycle is one of the major limiting factors in the development of local agriculture.

Fire has also profoundly affected the native forest ecosystem. Centuries of repeated fires have favored the aggressive, fire-tolerant grasses over trees. As a result, tens of thousands of acres of southern Guam's native forests have been converted to fire-prone savanna with the relegation of the remaining forests to moister, more protected ravines (fig. 4). Many valuable tree species have become quite rare and some are now endangered species (i.e., *Serianthes nelsonii*, *Cyathea lunulata* [Tree Fern], and *Cerbera dilatata*). Loss of forest habitat has also contributed to the decline of many species of birds and mammals.

All of Guam's fires are man caused: nearly 50 percent are set intentionally; the remainder are accidental (table 1). Deer poachers often burn the savanna and later return to hunt the animals (*Cervus unicolor mariannus*). Since poachers usually set fires in inaccessible locations, these uncontrollable fires usually burn over large areas. Off-road enthusiasts and betel nut (*Areca catechu*, a nut chewed by many Pacific islanders) gatherers often set fires to provide



Figure 3.—Fire-induced soil erosion has denuded large areas of Guam's wildlands.



Figure 4.—A remnant of native forest is protected in this moist ravine. The forest's patchy appearance is a direct result of fire-caused deforestation.

easier access to the wildlands. Careless cigarette smokers, trash burners, farmers, and children account for the remaining fires (fig. 5).

Guam's wildland fire suppression organization has received minimal territorial support because the economic value of the wildland watershed is not widely recognized. The Forestry Division has three aging, four-wheel drive trucks (converted military M715 personnel carriers) fitted with 200-gallon (757 L) slip-on pump units. Fire suppression operations are also restricted by personnel limits. Although local structural fire departments sometimes aid wildland firefighters when fire threatens a structure or utility poles, fires in Guam's interior are often left to burn because they are inaccessible to all firefighters but those with the most rugged equipment.

Since wildland fire on Guam has been such a common, accepted practice for so many years, it is difficult to achieve significant changes in attitudes; this is, nevertheless, one of the goals of the Forestry Division. An intensive and comprehensive public education campaign to educate Guam's citizenry about the effects of wildland fire has recently been implemented. With the help of a special Forest Service grant, a number of locally oriented brochures, television and radio Public



Figure 5.—Escaped trash fires cause nearly 20 percent of all Guam's wildland fires.

Service spots, and a slide-tape program have been created and released. A Fire Danger Rating prepared by the Forestry Division is now published and aired daily.

Print and electronic media have been used extensively to bring the topic of wildland fire before the public. In an effort to reduce the number of fires in two high-occurrence areas, a series of highway signs with fire prevention messages have been installed.

To combat wildland fires started from escaped farm clearance burns, the Division initiated a Standby-Burning Service for farmers. When a farmer wishes to burn his fields, he may request men and

equipment from the Forestry Division to help him properly control his fire. At the same time, the farmer is briefed on the need for fire prevention and the kinds of damage fire inflicts on the wildland resources.

After nearly a decade, the Forestry Division has made encouraging progress in the establishment of trees in degraded grasslands. Converting more grasslands to less flammable forest cover will permanently decrease the fire problem.

The Forestry Division has also had initial success in establishing fuelbreaks using succulent, fire-resistant groundcovers (i.e., *Wedelia*

biflora and others). Although plant establishment is labor- and machine-intensive, once installed, these fuelbreaks provide permanent fire protection to forest plantations.

Investigations are also continuing detailing fire behavior, fuel and savanna ecology, swordgrass eradication methods, and the development of locally applicable fire danger rating system. Attempts have been made to apply the National Fire Danger Rating System (Model N) and the Australian Fire Danger Rating System. Neither, however, has accurately predicted fire danger and fire behavior. A rather rough but surprisingly accurate system using fuel-stick readings, number of days since last rain, present day precipitation, and wind has been developed but needs to be refined.

Changing the attitudes of the Guamanian people regarding wildland fire and converting the savannas back to productive, less flammable forests will eventually reduce the problem of wildland fires on Guam. The fire problem must be effectively dealt with if Guam is to manage and benefit from its limited and badly degraded natural resources. ■

California's Unique Department of Forestry Fire Academy

Steve Brown

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The California Department of Forestry (CDF) Fire Academy at Ione, Calif., offers a unique range of courses in fire protection, fire prevention, law enforcement, and resource management. Over 1,000 department personnel train at the 40-acre center 35 miles southeast of Sacramento each year. Students from fire protection and law enforcement agencies throughout the State and Nation also attend courses at the CDF Fire Academy.

Fire protection courses at the Academy include Basic Fire Control, Emergency Command Center for Dispatchers, Heavy Fire Equipment Operation, Fire Management II, Air Attack Management, Field Administration, Equipment Management, and Human Relations for Fire Crew Supervisors (fig. 1). Each lasts from 1 to 6 weeks. Other fire protection courses are given as needed.

Fire prevention courses include Fire Prevention Analysis and Fire Prevention Education. CDF Fire Academy also offers a four-part series on arson investigation, Peace Officer Standards Training (POST), and advanced officer courses. In addition, speciality courses in management, affirmative action, soils, silviculture, environmental impact reports, employee-employer relations, and chaparral management are offered.

The Academy offers students a wide range of facilities. There are three laboratories: a fire pump lab,



Figure 1.—Wildland fire training at the CDF Academy.

a wildland fire lab, and a fire physics lab. The fire pump lab contains water pumping equipment, plumbing mock-ups, and a drafting pit. The Wildland fire lab

demonstrates the effects of fuel, weather, and topography with a sand table. Students solve fire control problems with small-scale air and ground fire equipment. Fire

chemistry and physics are taught in the fire physics lab. The physics lab is also used by law enforcement students to study the construction and residue of incendiary devices.

Two simulators provide students with realistic emergency situations and allow instructors to evaluate student performance under near real conditions. Situations are portrayed with the aid of audiovisual, closed circuit radio, and telephone systems. The dispatch simulator building contains a mock-up of a dispatch center. Students combat various emergencies including hazardous materials spills and wildland fire incidents using equipment in the fire simulator building.

The CDF Fire Academy also trains students in emergency vehicle operation (fig. 2) and off-road operations. Students practice driving and controlling fire equipment on a 6-acre compound, which contains a concrete skid pan and numerous driving courses. The compound may also be modified to train law enforcement students. The use of conventional and four-wheel drive engines in off-road incidents is taught on a 640-acre area. Fifteen pieces of fire equipment are available for student use.

The Fire Academy also has a 2-acre fireground training area, which has a two-story concrete block house for structural fire training, flammable liquid props, leaking flanges, a Christmas tree,



Figure 2.—Students learning emergency vehicle operation.



Figure 3.—Law enforcement techniques are also taught at CDF Academy.

and a 1-million-BTU propane backstop.

Additional training is available in vehicle extrication powerline in-

spection and emergencies, and the use of firearms (fig. 3).

For more information, call (209) 274-2426. ■

What Is This Thing Called NIIMS?

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Two systems for fire suppression are in wide use today in the United States—one developed by the Fire-fighting Resources of Southern California Organized for Potential Emergencies (FIREScope) and the other supported by the National Wildfire Coordinating Group (NWCG). The National Interagency Incident Management System (NIIMS) is a synthesis of both fire management models and goes a step further. It is adaptable to all types of emergencies.

Background

During a 13-day period in 1970, 16 lives were lost, 700 structures were destroyed, and over one-half million acres were burned in California. Although all of the fire-fighting, law enforcement, and emergency agencies throughout the State cooperated to put out the fires, communication and coordination problems hampered their effectiveness. As a result, Congress appropriated funds to strengthen fire suppression command, control, and research.

Members of local, State, and Federal agencies in California formed FIREScope to work together on all types of emergencies. To implement their cooperation, FIREScope members developed the Incident Command System (ICS) for fire suppression to deal with the wide range of emergencies, from small incidents to major situations.

Until its members completed a study of fire suppression models in 1980, NWCG strongly recommended the Large Fire Organization (LFO) fire suppression system. The NWCG was established in 1972 to coordinate fire management programs of participating Federal and State agencies, and to provide a means for the agencies to work together constructively to avoid unnecessary duplication of effort. It developed the National Interagency Fire Qualifications System (NIFQS), which describes how firefighters must be qualified and certified to perform within the LFO. NIFQS, combined with LFO, is being used by most Federal, and some State and local, fire protection agencies as a complete fire suppression system.

Recognizing that two parallel fire management systems were in use, NWCG commissioned a study of the FIREScope/ICS and LFO/NIFQS systems in 1980. NIIMS is the product of the study. Its organization closely resembles the LFO and the ICS. And it merges the qualification, certification, and training standards of NIFQS with the managerial and operational components of the ICS.

The Advantages of NIIMS

By combining elements of the existing fire and emergency management systems, NIIMS is expected to reduce fire losses of nat-

ural resources and property, and cut the time and cost of fire suppression. NIIMS offers participating agencies certain desirable features:

- It provides common standards in organization and procedures, and also provides flexibility for meeting local needs.
- It can be adapted to any type of emergency to which fire protection agencies would be expected to respond.
- It is applicable to small incidents occurring in single jurisdictions and handled by single agencies.
- It meets the requirements of a small incident or expands to meet the demands of an escalating fire situation, involving several jurisdictions, many agencies, and two or more separate large incidents.
- It maintains the autonomous jurisdictional responsibility of each agency, regardless of its size.
- It stresses the concepts of Total Mobility of firefighting personnel from all cooperating agencies and of the response of Nearest Forces to any incident, independent of jurisdictional boundaries.
- It is adaptable to new technology.
- It allows the maximum use of previously developed qualifications, standards, and certification for fire management.
- It provides for regional development of a qualification and

certification system to meet regional needs.

- It is simple and logical enough to ensure low costs for training and maintenance.

- It incorporates widely known and used management concepts.

The Management Concepts That Make NIIMS Work

Functional Management. The five essential tasks in a fire or emergency incident are command, operations, planning, logistics, and finance. The Incident Commander is responsible for all five functions, and when the size of the incident requires, he assigns section chiefs for planning, operations, logistics, and finance.

Unified Command. Under the unified command concept, agencies or individuals who have jurisdictional and, in some cases, functional responsibility at the incident help determine overall objectives, select strategies to achieve those objectives, and appoint the Incident Commander. The Incident Commander is responsible for preparing an action plan based on the objectives and strategies.

Management by Objectives. Once the objectives for an incident are decided upon, direction moves from the top down. The objectives are written down and available for all participants to read and understand.

Consolidated Action Plan. Every incident requires an action plan. Small, single jurisdictional incidents may only require the action plan to be in the mind of the Incident Commander. Large, multi-jurisdictional incidents, however, require a written plan.

Designated Incident Facilities. The traditional practice of locating all facilities and resources at one place is optional in NIIMS. For instance, the command post (the center of incident management) and the incident base (the site of all support activities) in a major incident may or may not be at the same site. Other facilities such as camps, staging areas, helibases, and heliports are established if and where they are needed.

Management of Tactical Resources. Under NIIMS, tactical resources can be managed in four ways: as single resources, task forces, strike teams, or combinations of the three. A single resource is an independent unit such as a helicopter, engine, or plow unit with the personnel to operate it. It may be used in any number of situations to accomplish a mission. Task forces are made up of a combination of unlike resources such as an engine, bulldozer, and a hand crew with a leader and common communications designated to perform a specific task. Strike teams are composed of single similar resources, such as five engines

or two hand crews, with a leader and common communication.

Span of Control. The span of control is a supervising management concept. Generally the best supervised grouping would be from three to five individuals, crews, units, engines, etc. There are times when certain factors such as safety, type of incident, terrain, weather, or communications might require a different grouping.

Common Terminology. It is essential that all cooperating agencies use standard terminology for equipment and manpower units. Such standardization facilitates effective communication among all participating agencies.

Integrated Communications. An important part of planning for any major multi-jurisdictional incident is to have a communications system that can unite all tactical and support units and maintain communications discipline. All communication must be in plain English, using commonly understood terminology.

Conclusion

Most of the concepts in NIIMS are not new. The system is a refinement of several existing fire suppression and emergency management models. The costs associated with the development of training packages and the actual training itself will be more than offset by the

Organization of NIIMS Incident Command

quality and effectiveness of fire-fighting personnel who will be available quickly to local, State, and Federal agencies in emergencies. NIIMS also provides for the effective use of special skills from all participating agencies.

NIIMS, as a nationally applicable emergency management model, can have a major impact on losses from wildfire by directing the effective use of the resources of all fire protection agencies.

For further information, contact: Director, Cooperative Fire Protection, USDA Forest Service, P.O. Box 2417, Washington, DC 20013. ■

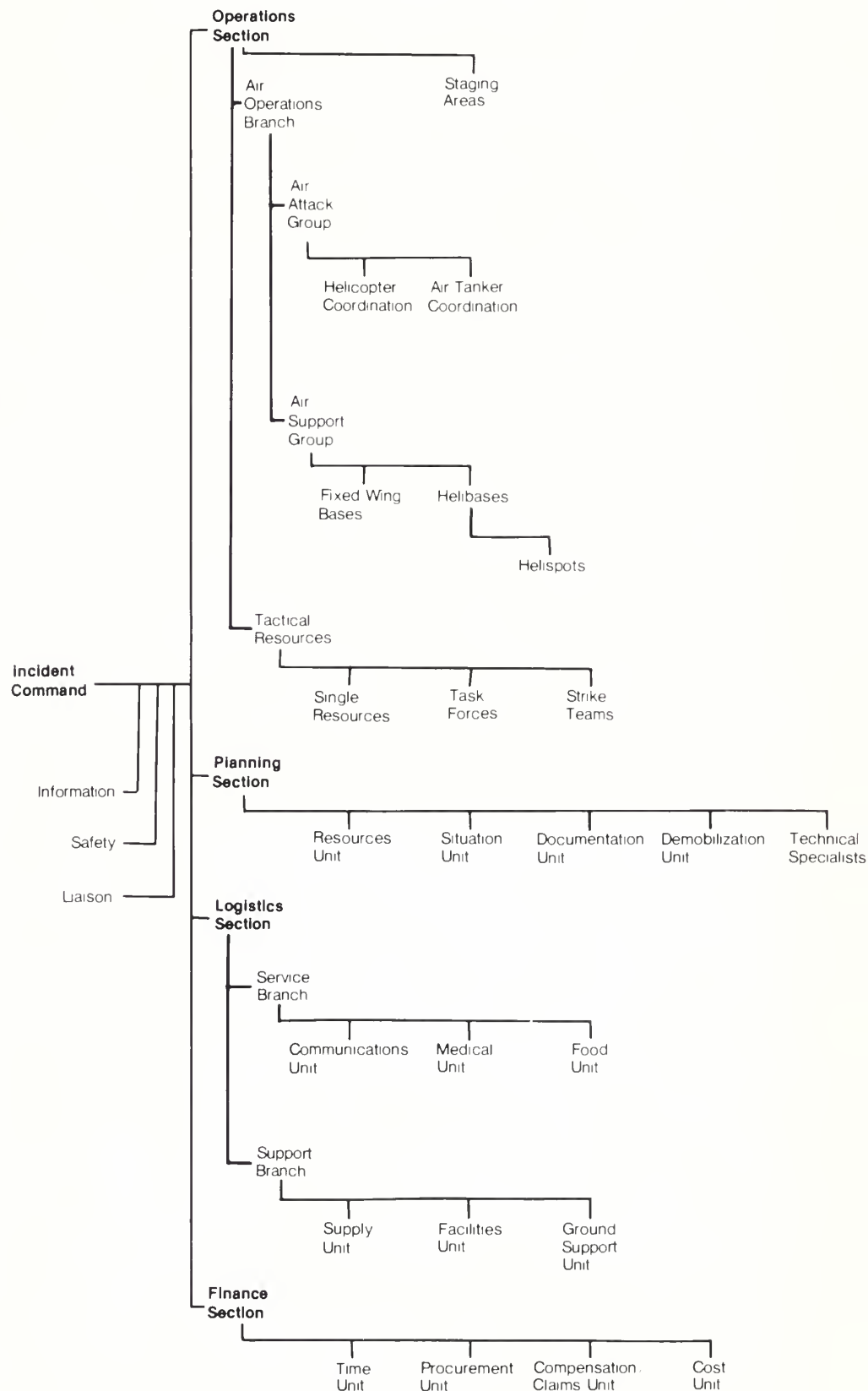


Figure 1.—NIIMS Incident Command Organization Chart.

Fire Retardants and Aerial Delivery Systems—Performance and Use ¹

Charles W. George

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Airtanker and Retardant Use

Use of fixed-wing aircraft to apply fire retardants on wildfires has been common practice since the mid-fifties. Since 1970, major user agencies—USDA Forest Service, California Department of Forestry (CDF), Bureau of Land Management (BLM), and Bureau of Indian Affairs (BIA)—have aerially applied more than 20 million gallons of retardant annually. Delivery of this retardant requires nearly 10,000 hours of flight time (fixed-wing aircraft) each fire season. The majority of retardant is used for initial attack on newly detected fires. The greatest value and most effective use of airtankers has been in retarding or stopping the spread of fires before they become large. Thus to use air tankers most effectively, retardant bases and airtankers are strategically located throughout areas of the greatest fire potential, highest risk, and highest value. Airtankers are available on short notice (usually 15 minutes) throughout the fire season. Although airtankers are contracted and assigned to specific retardant base locations, they are moved around as fire seasons and fire danger warrants.

For the 1981 fire season, 43 airtankers were contracted by the USDA Forest Service, 21 by the CDF, and 16 by BLM and BIA. Requirements for type and size of aircraft vary for each location, depending on the fuel and fire characteristics in the area, location of the retardant base in relation to potential fire locations, limitations for the airport, aircraft performance, or other management considerations. Aircraft are owned and operated by private operators, who are competitively awarded contracts for specified times and locations (with the exception of 17 S2F airtankers belonging to the CDF, which contracts for operation and maintenance). The duration of airtanker contracts varies from 100 to 170 days, depending on the fire season. A minimum contract period is guaranteed (90–120 days), with provisions to extend availability to the pre- or post-fire season periods. Other than in California where longer fire seasons occur with regularity, contracts are often split between two or more locations. (For example, an airtanker may receive a contract for Knoxville, Tenn., from March to mid-May; Albuquerque, N. Mex., from mid-May to early July; and for Missoula, Mont., from July to mid-September.) The amount of actual flight time airtankers are utilized on fire missions is quite variable, depending primarily on fire activity in the

areas served by the base for contract and, to some extent, the severity of the fire season nationally requiring some reallocation of resources. Flight time for an airtanker during a season with the agencies mentioned is normally between 100 and 140 hours, a relatively small amount of flying time for the length of availability required.

Airtankers are contracted from a national fleet of privately owned aircraft that have previously been evaluated and determined to meet certain design and performance criteria. In 1972, fire management agencies established an Airtanker Screening and Evaluation Board (the name later changed to Interagency Airtanker Board), for the purpose of developing a process, procedures, and criteria for evaluating proposed new airtankers. The Interagency Board has supported research and development programs to improve both aircraft and delivery systems and to coordinate related efforts of its members. As a result, mandatory criteria and a program were developed to screen and approve aircraft for use by fire management agencies. There are presently 117 aircraft on the approved airtanker list. The airtankers consist of 12 different types, with retardant carrying capacities as shown in table 1. The aircraft (with the exception of the S2F's) are owned by 16 operators.

¹Reprinted with permission from *Aerial Applicator* Vol. 19(8), 1981.

Also available to fire management agencies in certain situations are Air Force Reserve or National

Table 1.—List of approved airtankers

Aircraft type ¹	Number in fleet	Capacity ²
		gal
S2F	17	800
F7F	4	833
B26	12	1,000–1,200
PBY	4	1,056–1,250
PV2	5	1,056
B17	10	1,806
DC4/C54	18	2,028
C119	11	2,028
PB4Y2	7	2,200
DC6	10	2,233–3,000
P2V	8	2,450
DC7	11	2,744–3,000

¹ Includes all models/modifications.

² Capacity in gallons calculated using a retardant weight of 9 lb/gal

Guard C-130 aircraft equipped with a modular pressurized dispensing system termed Modular Airborne Firefighting System (MAFFS). MAFFS was developed by FMC Corporation under contract to the U.S. Air Force in a cooperative effort with the USDA Forest Service, which subsequently was granted funds to purchase seven additional units. The MAFFS units, stored and maintained with several selected western National Guard and Air Force Reserve units, can be called upon when all contract aircraft are committed, either due to active fires or extreme fire danger. (Such situations are infrequent, of limited duration, and are the result of

many large fires associated with high risk and damage potential.) When requested, MAFFS is readied within 24 hours, and usually operates from large commercial or military airport facilities where portable retardant mixing bases are set up. The MAFFS units have been activated eight times since they were available in 1974 (fig. 1).

The USDA Forest Service, Intermountain Forest and Range Experiment Station, Ogden, Utah, has a continuing research program on retardant effectiveness and aerial delivery systems at the Northern For-

est Fire Laboratory, Missoula, Mont. The program is divided into several study areas:

- Combustion-retarding effectiveness of retardants
- Physical-chemical or rheological properties of retardant
- Delivery systems
- Retardant-caused corrosion
- Environmental impact

The studies are aimed at understanding the effect of these variables so that the most effective delivery system, retardant formulations, and procedures for use can be identified.

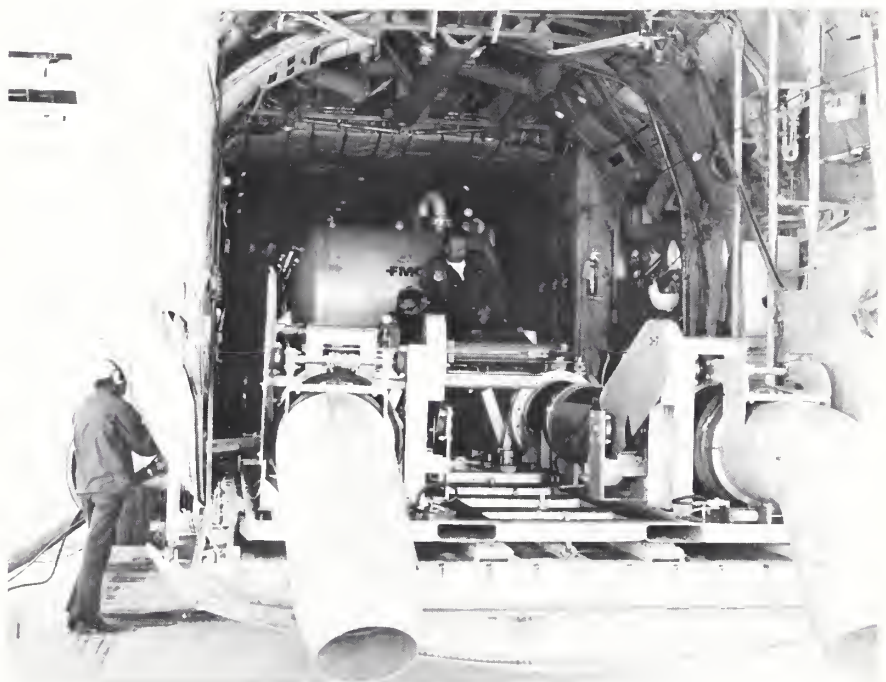


Figure 1.—MAFFS unit aboard C-130 airplane is serviced.

Aerial Delivery Systems Performance

Recent studies have shown that the flow of retardant from the aircraft tank is the most important variable in determining the retardant distribution on the ground. The aircraft is a platform that supports the tank and gating system and only indirectly affects performance. The flow rate (volume of retardant per second released for each second of aircraft travel) is influenced by tank geometry, door area, door-opening rate, and venting, and can be controlled or modified. Flow rate and tank configuration together determine the retardant distribution in a complex way that is difficult to model and visualize. But generally speaking, if the fluid breaks up immediately on release from the tank, the distribution is almost entirely defined by flow rate. Immediate breakup occurs when the flow rate is low or the length of fluid or tank is short compared to width. If tank evacuation is fast, distribution is determined primarily by retardant breakup in flight and the inertia of the retardant. Patterns from most airtankers, however, represent a combination of effects, where flow rate organizes the retardant mass distribution for flight. The fluid then travels down range and is deformed by counteracting dynamic pressure. At this point, instabilities developing at the frontal surface of

the fluid shatter the remaining mass. Simultaneous surface erosion of the retardant results in a cloud of retardant whose size and distribution are determined by existing shear forces and the rheological (physical-chemical) properties of the fluid.

Tank shape and fluid exit geometry determines the shape of the retardant as it is released. Aerodynamic shape affects retardant breakup during initial phases of the drop and in turn the resulting pattern. Fluid released at high flow rates, for example, from long, thin tanks will provide longer patterns of effective coverage than short, wide tanks. This results in less exposed frontal surface, and requires longer time for deformation and breakup. The front surface of the dropped load protects the trailing fluid like an ablative shield as it deformed and stripped away, making up the tail end of the ground distribution pattern. The fluid from the rear section of the tank receives the greatest protection and comprises the retardant that is projected farthest.

A model has been developed to simulate retardant drop patterns based on the retardant flow rate, volume, and release sequences. The model increments flow rate, flies each increment to breakup, distributes the retardant in space, displays the distribution on the ground, and provides a marginal ground distribution. Drop height, aircraft

speed, and type of retardant simply modify the performance. Although effect of tank geometry and the shape of the fluid on release have not been fully incorporated, fairly accurate estimates of performance under a wide range of conditions can be achieved. Calculated results from the pattern simulation model in conjunction with actual drop test data were used to validate the model and to evaluate the effect of variables such as drop height. Increased drop height, for example, reduces the peak coverage level and momentum of the fluid and, to a point, increases pattern width.

Aircraft speed affects retardant distribution. The effect of speed is dependent on fluid shape. When the tanks are of moderate length (4 to 6 ft), aircraft velocity has little effect on coverage level. Flying faster generally reduces peak coverage levels, increases pattern momentum, and increases low coverage lengths. But an adequately tanked aircraft can develop effective patterns at safe power levels up to about 170 knots before air speed begins to degrade patterns significantly. Nevertheless, accuracy and consistency of performance are maximized when drop speeds are held within a relatively narrow range.

Results of research into aerial delivery systems and retardants have been incorporated into airtanker performance guides and re-

tardant coverage slide charts. The guides and slide charts, which are similar to an instruction manual for an instrument, are generated by use of the simulation model and quantify the capability of specific airtankers to deliver retardant to the fuel. The development of airtanker guides begins with the collection of flow rate data on the tank and rating system by means of a float gauge that records the level of the upper retardant surface in a single tank as a function of time. These data are converted to gallons released as a function of time from an analysis of tank geometry. The flow rate data are entered into the computer simulation model that predicts the ground distribution patterns. Data from a series of simulated test flights are then digested, summarized, and transformed into a performance guide. The guides present performance data in graphs and tables that will help airtanker pilots, air attack specialists, and ground personnel obtain optimum retardant coverage under various conditions.

Fire Retardant Formulations and Effectiveness

Fire retardants are a mixture of ingredients, each of which imparts desired chemical or physical characteristics to the solution. The primary component is the fire-retarding chemical, usually an ammonium sulfate or phosphate. In ad-

dition, thickening agents, such as guar gum, are incorporated to minimize evaporation and drift during the drop and as a result of the drop height and winds. Bactericides, or spoilage inhibitors, are added to lengthen the storage life of retardant formulations containing organic thickeners. Corrosion inhibitors are added to prevent damage to the mixing, transfer, and storage equipment as well as to the aircraft and tank and gating system. Coloring is usually added to serve as a marker so that drops can be identified.

Retardants containing an active fire-retardant salt are identified as long-term fire retardants, those which due to the fire inhibiting chemical are nearly as effective when totally dry as when wet. Retardants containing only a thickening agent to improve drop characteristics and possibly retentive properties on fuels are called short-term fire retardants. Short-term retardants are only effective when wet; when fully dry (usually less than an hour after application) they offer no significant retardancy. Because of superior effectiveness, especially during high fire danger, long-term retardants have seen the most use since the early sixties. Long-term retardancy also allows fire-proofing fuels ahead of the fire front as well as other tactical uses requiring the application to be effective for several hours or more. Nevertheless, short-term re-

tardants are presently receiving more attention, because of the rapidly escalating costs of long-term retardants and confidence that procedures can be developed for effective use.

The performance of thickened retardants is based on the type of thickening agent they contain, which affects retardant breakup, surface erosion, and survival. Retardant formulations currently in use have been classified into two major performance categories, gum-thickened retardants and water-like retardants.

Gum-thickened retardants are highly cohesive and exhibit elastic properties and a high viscosity under shear that resists breakup. Under high shear conditions, a gum-thickened retardant will form larger droplets than a water-like retardant, and thus provide less surface area to evaporate and a greater resistance to wind deflection. This fact has been verified during actual drop studies where the droplet size and impact patterns have been quantified using both photographic techniques and rotating samplers. Such studies have been used to verify previously developed retardant breakup/dispersion models that correlate to rheological properties of the fire retardant with various aerial delivery characteristics and performance.

The models provide a tool that may in the future allow retardant

formulations to be designed to produce droplets of gum-thickened retardant that are less susceptible to evaporation and wind drift and have the potential of improving performance and safety by increasing effective drop heights.

Conclusion

Use of aircraft and retardants for combating wildfire is a sizable business and expense. Adapting and utilizing new technology is a formidable challenge. Aerial delivery operations and specifications

for aircraft tank and gating systems, and retardants should be continually evaluated and improved. Putting present knowledge of retardants and delivery systems to use can undoubtedly lead to safer and more economical application. ■

Preliminary Guidelines for Broadcast Burning Lodgepole Pine Slash in Colorado

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Lodgepole pine (*P. contorta*) is a highly important species in forest management in Colorado. Combinations of a very widespread range, considerable acreage supporting large volumes, and wide ecologic amplitude contribute to the high value of this species (Wellner 1975). Because of its importance, lodgepole pine stands are intensively managed for wood fiber production in northern Colorado. But on many sites, insufficient natural regeneration is occurring following timber harvesting. Artificial regeneration following machine piling and burning also fails to produce desired stocking levels.

The depth of forest floor duff layers in these stands appears to be the principal cause of regeneration failure. The germination of lodgepole pine seed is favored by full sunlight; seedlings develop best in mineral soil or disturbed duff free of competing vegetation (Pfister and Daubenmire 1975). Duff layers common to lodgepole pine stands in the Intermountain Region are usually shallow and seldom average more than 2 in (5 cm) (Brown 1975). In northern Colorado, Alexander (1979) found duff layers as deep as 3.6 in (9 cm). Depths exceeding 4 in (10 cm) were found in some of the clearcuts burned in this study. Seeds from surrounding trees apparently germinate in duff rather than mineral soil and perish during droughty summer months. Machine piling followed by burn-

ing fails to scarify enough area for natural restocking. Planting in thick duff layers becomes labor intensive and costly.

The importance of fire in establishing proper site conditions for lodgepole pine regeneration is well known (Brown 1975). Broadcast burning can destroy unopened cones present in slash, and Alexander (1966) observed less natural regeneration on burned plots than on either undisturbed or disturbed mineral soil plots. However, Lotan and Perry (1976) state that broadcast burned areas may be the most suitable for germination and survival of artificially applied seeds, although true ash surface effects on germination were not reported. In Colorado, little research has been conducted, or experience gained, regarding burning prescriptions, firing techniques, and duff reduction in lodgepole pine stands. Adams (1972) compared natural regeneration following broadcast burning with other slash disposal methods but presented no information pertaining to the actual burning. Data collected during experimental fires in lodgepole pine slash have been used to develop preliminary guidelines for prescribed burning in southwestern Alberta (Quintilio 1970, 1972). These guidelines relate rate of head-fire-spread and depth-of-burn to the appropriate components of the Canadian Forest Fire Weather Index System.

In an attempt to improve regeneration success following logging, personnel from the USDI Bureau of Land Management (BLM) conducted broadcast burning in lodgepole pine clearcut areas. This report summarizes the results obtained from the initial prescribed burning trials.

Site Description and Methods

Lodgepole pine forests represent the principal vegetative type present. Prior to logging, stands were comprised of an average of 218 merchantable and 138 cull stems per acre. Harvest operations removed a gross volume of nearly 11,000 board feet per acre and were completed during the summer of 1979. Following timber removal, all remaining standing stems were felled into the burn units. Prescribed burning was carried out on numerous clearcut blocks ranging in size from 3 to 10 acres (1.2-4 ha) with results presented from three representative units.

Downed woody fuel accumulations were measured by the planar intersect method (Brown 1974). Permanent fuel inventory transects were established along lines running upslope through each burn unit. Duff measurements taken along these transects refer to the sum of the fermentation layer (F), material starting to discolor and break down because of weather and microbial action, and the humified layer (H), where decomposition has advanced.

Weather conditions were measured on the site prior to and during burning with the components of a standard belt weather kit. Variables measured include: dry bulb temperature, relative humidity, wind speed, and wind direction. Fuel moisture contents (10-hour time lag) were measured by weighing a standard array of $\frac{1}{2}$ in (1.27 cm) Ponderosa pine fuel sticks (Deeming, et al. 1977).

Prescribed burning was carried out during late September and early October. On all units ignition was started at 1300 h each day with drip torches used as ignition devices. Firing techniques used include: strip head, backing, and ring center fires.

Preburn Fuel Description

As is characteristic in lodgepole pine forests following timber harvesting, logging residues accounted for the majority of downed woody fuels (fig. 1). In all units burned, fuel particles in the greater than 3-in sound size (7.6 cm) class comprised the majority of slash fuels (fig. 2). Fuels in the greater than 3-in (7.6 cm) rotten size class were noticeably absent in all burn units (fig. 2). Preburn measurements showed that Unit A contained the greatest fuel concentration, totaling 65.64 tons per acre (29.28 tonnes per ha) of downed woody materials. The sparsest concentration of fuels, 17.60 tons per acre



Figure 1.—Preburn fuel conditions.

(7.8 tonnes per ha) was found in Unit B before burning. Unit C contained 40.68 tons per acre (18 tonnes per ha) of woody fuels.

Weather Conditions

Weather measurements indicated that conditions during burning of Unit A involved the highest relative humidity and lowest wind speed and fuel moisture encountered during all burning (table 1). Conditions changed slightly during the burning of Unit B with decreases in temperature and relative humidity while wind speed increased. Fuel moisture in this unit was the highest measured during all burning. Weather conditions experienced while burning Unit C in-

cluded the warmest temperature, lowest humidity, and highest consistent wind speeds (table 1).

Fire Description

No precipitation fell on the areas for nearly 3 weeks before burning. In units where strip head fires were used, uphill control lines were burned out initially, then strips of 15 to 100 ft (4.6–30 m) in width were ignited downslope. Strip head fire intensities varied with the strip width. Lowest intensity was observed where the fires backed downhill. Maximum intensity, highest flames, and greatest vertical convection occurred where head fires from one strip and backfires from a previous strip

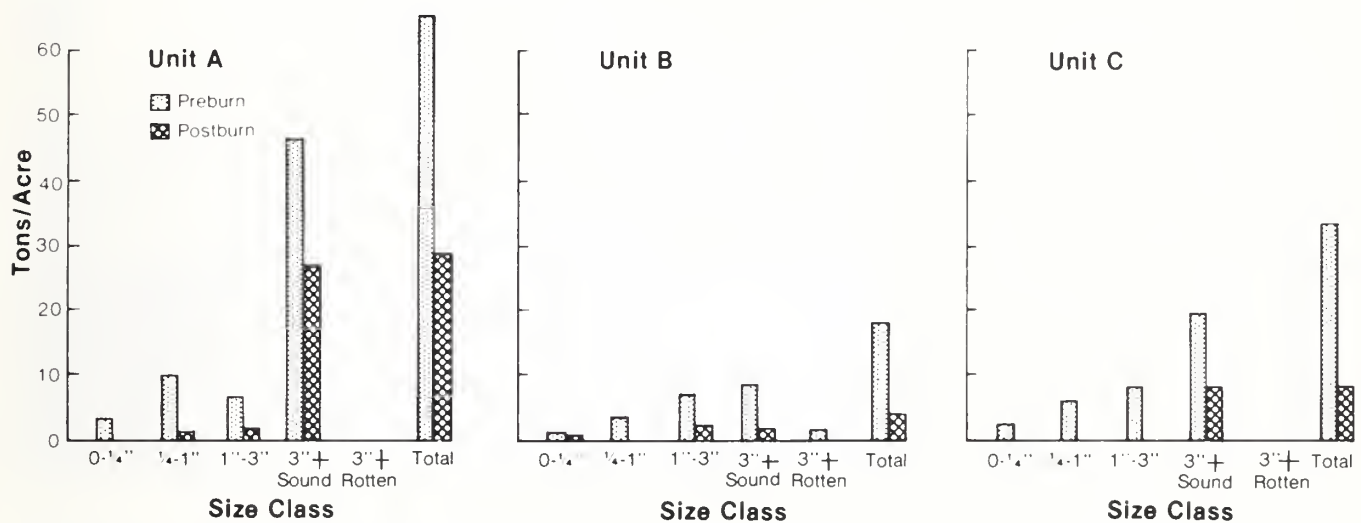


Figure 2.—Concentration of fuels in burned units.

Table 1.—Weather measurements

Unit	Temperature	Relative humidity	Wind speed	Wind direction	Fuel moisture (10 hr. time-lag)
	$^{\circ}\text{F}(^{\circ}\text{C})$	Percent			Percent
A	55 (13)	40	2	SE	9.5
B	54-56 (12-13)	31-37	0-6	NW	12.5
C	70 (21)	25	3-5	SE	11.5

burned together (fig. 3).

The ring center firing technique created a situation where indrafts drew heat away from surrounding tree crowns and fuels. Firebrands generated by this high intensity fire were drawn upward with the smoke column and traveled considerable distances before coming into

contact with unburned fuels. Maximum distances traveled by these firebrands were not estimated and no spot fires occurred during use of this firing method. Because of the lack of firebrand spotting this method was extremely successful on flat areas completely surrounded by live trees. However, the ex-

treme heat generated resulted in crown scorch and mortality of trees around the perimeter.

No problems occurred with mop-up of any units. Spot fires caused by burning embers transported across the firelines occurred most often when temperatures were above 70°F (21°C) and relative humidities below 25 percent. Burning during these conditions required more holding forces and maintaining control of the burn became quite labor intensive.

Fuel Reduction

Fuel consumption by prescribed burning varied with the firing techniques used, weather conditions, preburn fuel loading, and duff depth (fig. 4). In Units A and C greatest reductions were observed in all size classes less than 3 in (7.6 cm) (fig. 2). Unit B, which had the lowest amount of fuel greater than 3 in (7.6 cm) (chiefly sound), had the highest percent reduction of any unit in this size class.

Total fuel reduction in Unit A was 57 percent and left postburn levels of downed woody fuel at 28.5 tons per acre (12.7 tonnes per ha) (fig. 2). Unit B postburn fuels totaled 8.81 tons per acre (3.9 tonnes per ha), a reduction of 83 percent. Burning in Unit C resulted in a reduction of 75 percent, leaving the postburn level at 9.36 tons/acre (4 tonnes/ha). Reductions of 100 percent were observed in all size classes less than 3 in (7.6 cm) in this unit.

Depth of burn varied from 0.44 to 3.68 in (1–9 cm) (table 2). Following burning, duff depths were 0.6, 0.4, 0.06 in (1.5, 1.0, 0.1 cm) for Units A, B, and C, respectively. Duff reduction exceeded 40 percent in all three clearcuts and was greatest in Unit B. (Unit B had the greatest depth prior to burning.)

Summary

Prescribed broadcast burning of



Figure 4.—Postburn conditions of lodgepole pine clearcuts.

clearcut logging slash successfully and safely reduces slash buildups

and forest floor duff layers, and prepares sites for natural and arti-

Table 2.—*Preburn duff loading/depth and duff removal by prescribed burning*

Unit	Weight per acre ¹	Depth	Reduction	Depth of burn
	<i>Tons</i>	<i>Inches (cm)</i>	<i>Percent</i>	<i>Inches (cm)</i>
A	15.52	1.07 (2.7)	44	0.47 (1.1)
B	59.16	4.08 (10.3)	90	3.68 (9.3)
C	7.25	0.50 (1.27)	88	0.44 (1.1)

¹ Computed by the formula: mean depth × 14.5 = tons per acre (on file Northern Forest Fire Lab, Missoula, Mont.).

ficial regeneration in Colorado lodgepole pine communities. Because lodgepole pine regeneration is prolific following wildfires, prescribed burning is a method of site preparation which can approximate natural conditions.

When adequate surface fuels are present to support fire spread, strip head fires and backfires can be used. Strip head is the most versatile method of prescribed burning and allows the firing boss to control the level of fire intensity (Martin and Dell 1978). Backfires are the gentlest and slowest moving fires (Martin and Dell 1978). Successful backfires require lower fuel moisture content and better fuel continuity than head or strip head fires.

Ring center fires can be used where heavy fuel buildups are present on relatively flat slopes. This firing technique develops high intensity fires, rapid burnout, and vertically dispersed smoke. Martin and Dell (1978) state that this technique can be used where available fuels can produce sufficient intensities to overcome winds and where

there is no concern for live trees inside the burn unit.

Prescribed broadcast burning of clearcut logging slash in Colorado lodgepole pine forests will produce satisfactory results when carried out under the following conditions:

Temperature (dry bulb)	54–70 °F (12–21 °C)
Relative humidity	25–40 percent
Wind speed	0–6 mi/h
10 hr. time lag fuel moisture	9.5–12.5 percent

Although desired results were achieved with this prescription, adequate advance preparation and control planning can permit completion of prescribed burning on specific sites under different weather conditions. For example, while the prescription lists wind speed as 0 to 6 mi/h, subsequent fires were safely carried out with wind speeds as high as 18 mi/h.

Weather conditions pose one of the principal limitations encountered when attempting to use fire as a tool in forest management. In northern Colorado during the peak burning period, low humidities and variable, gusty winds are prevalent. Frequent high temperatures must

also be considered because they can be responsible for increases in fire intensity and the likelihood of erratic fire behavior due to the preheating of fuels, decrease in humidity, and increase in unstable air from ground heating (USDA Forest Service 1973). These conditions drastically limit the number of suitable burning days. Questions also arise concerning the effects of fire on growing conditions for artificial regeneration, particularly surface soil temperature changes. Endean and Johnstone (1974) have attributed better survival and growth of planted stock to slash removal and seedling placement. Fuel and duff consumption by fire can also facilitate easier, more efficient planting and lower susceptibility to mortality from droughty summers.

Leaving residual trees rather than felling them may provide a natural seed source. Broadcast burning destroys the potential seed source near the ground but can generate sufficient heat to open serotinous cones of standing trees. However, Endean and Johnstone (1974) have suggested that lodgepole pine seed trees show no promise as a seed source in combination with prescribed burning, because the seed trees are not sufficiently windfirm or fire resistant and require heat above the safe hazard level to open the cones. But, where long-term survival of residual trees is not a prerequisite to burning,

the use of broadcast fire may stimulate the opening of serotinous cones.

While the results and suggestions presented in this report are preliminary, it appears that prescribed fire can be used for reduction of slash fuels and site preparation in clear-cut lodgepole pine forests. Perhaps these preliminary guidelines will be a starting point in the development of sound programs of fire use to achieve desired forest management objectives.

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